Table 1. Target Effluent Concentration (TEC) definitions for lagoons

TEC	Options for Facultative Lagoons	Options for Aerated Lagoons
$TN_{7.0}$	Aeration + denitrification filters (*retrofit:* existing lagoon system retained/modified)	Denitrification filters (*retrofit:* existing lagoon system retained/modified)
$TN_{7.0}$	MLE Process (*replacement:* new mechanical treatment plant)	N/A
$TN_{3.0}$ + $TP_{0.1}$	ENR + chemical precipitation + tertiary filtration (*replacement:* new mechanical treatment plant)	ENR + chemical precipitation + tertiary filtration (*replacement:* new mechanical treatment plant)
$TN_{3.0}$ + $TP_{0.05}$	Spray irrigation system (*retrofit:* existing lagoon system retained/modified)	Spray irrigation system (*retrofit:* existing lagoon system retained/modified)
$TP_{0.1}$	Chemical precipitation + tertiary filtration (*retrofit:* existing lagoon system retained/modified)	Chemical precipitation + tertiary filtration (*retrofit:* existing lagoon system retained/modified)

MLE = Modified Ludzack-Ettinger process. ENR = enhanced nutrient removal, which includes some type of improved MLE-based biological nitrogen removal process and enhanced biological phosphorus removal (EBPR).

An effluent TN of 7-8 mg/l (for simplicity, we generally refer to this as $TEC_{7.0TN}$ in this document) was assumed to be achievable by amending/retrofitting the existing system with denitrification filters after lagoon treatment, provided the lagoon was already achieving nearly complete nitrification (i.e., an aerated lagoon currently demonstrating relatively high concentrations of effluent nitrate and low concentrations of effluent ammonia). Cost estimates for retrofitting unaerated, facultative lagoons assume that an aeration system would be installed in the existing lagoon(s) prior to a new biological (denitrification) filtration system. Costs for this first *add-on* option could be considered reflective of costs associated with other non-replacement approaches, like those addressed in Appendix 1. For comparison, considering that retrofitting may not be feasible at some lagoons, we provided a second option for $TEC_{7.0TN}$ which uses cost data for new MLE-based mechanical WWTPs. We assumed that a TN of 3.0 mg/l could be met by replacing the lagoon with a new mechanical enhanced nutrient removal (ENR) plant or by removing the existing direct surface water discharge and using spray irrigation instead (while retaining the lagoon for treatment). The latter option assumes that the spray irrigation site/soils and design are sufficient to further treat lagoon effluent to 3.0 mg/l total nitrogen (not factoring in any dilution) prior to the effluent reaching surface waters via subsurface (vadose zone and groundwater) flow.

For phosphorus removal, we defined two TECs, since these increments of TP reduction typically require significant differences in technology and associated costs. $TEC_{0.1TP}$ generally assumed the addition of conventional chemical precipitation and tertiary filters (e.g., moving bed filters, media filters, cloth/screen filters). For BNR process options with $TEC_{0.1TP}$, we assumed that EBPR would be both viable and cost effective for TP removal, with polishing by chemical precipitation (and tertiary filtration). We further assumed that spray irrigation would be capable of meeting an effective (i.e., before dilution) TP concentration of 0.05 mg/l prior to reaching a surface water, based on phosphorus sequestration within the soil matrix.

We have not taken into account any collection system improvements that may be required, as mechanical WWTPs can be more sensitive to influent flows impacted by inflow and infiltration (I/I) than lagoons which typically have enough storage capacity to mitigate wide ranges in flow.

Our approach to costing lagoon retrofit/replacement options was to develop a relatively small set of “model” lagoons that represent the range of systems under consideration. This approach has been used by the authors of several reliable costing references (e.g., Utah Division of Water Quality, 2010; Washington State Department of Ecology, 2011). Since costs based on the references used are largely a function of plant size (i.e., reflecting economies of scale), we divided the 51 minor lagoons into four flow ranges based on representative percentiles of the design flows for the population of lagoons (Table 2). Median (i.e., 50^{th} percentile) flow for the major lagoons was used to generate a single model lagoon to represent the three major Montana lagoons.

Table 2. Montana minor and major lagoon design and actual flows and ranges

NPDES Permit Type	Percentile	Design Flow (Range), MGD	Actual Flow (Range), MGD
Minor	25^{th} %	0.050 (0-0.163)	0.038 (0-0.099)
Minor	75^{th} %	0.275 (0.164-0.388)	0.159 (0.100-0.230)
Minor	90^{th} %	0.400 (0.339-0.999)	0.300 (0.231-0.628)
Major	50^{th} %	1.450 (>1.000)	0.955 (>0.629)

Because the one nitrifying lagoon was a minor facility falling into the 90^{th} percentile flow range, a fifth model lagoon (Model 4) was provided at this level, as illustrated in Table 3.

Table 3. Model lagoon characteristics

Model	Design Flow MGD	Actual Flow MGD	TN[1] mg/l	TP[1] mg/l	Type
1	0.050	0.038	15.0	5.0	Non-nitrifying
2	0.275	0.159	15.0	5.0	Non-nitrifying

3	0.400	0.300	15.0	5.0	Non-nitrifying
4	0.400	0.300	15.0	5.0	Nitrifying
5	1.450	0.955	15.0	2.5	Non-nitrifying

[1] Average starting TN and TP concentrations - based on the facility characterization data - are provided mostly for informational purposes, as they have little bearing on the treatment options and costs reported.

Where multiple reliable references address similar TECs (and similar existing facility "starting points"), we generally averaged the capital and O&M costs from the multiple references or options to determine a likely cost for achieving a certain TEC for final reporting purposes.

Two $TEC_{7.0TN}$ options are provided for lagoons associated with Models 1, 2, 3 and 5, and two $TEC_{3.0TN+0.1TP}$ options are provided for lagoons associated with Model 1. One $TEC_{7.0TN}$ option was constructed by adding costs for adding aeration and adding denitrifying filters to existing lagoons -- this could be considered a "retrofit" option. For this $TEC_{7.0TN}$ option, we added the costs associated with needed retrofits from two references: one addressing costs for adding aeration, and one addressing costs for adding denitrifying filters. The other $TEC_{7.0TN}$ option was developed based on cost data from Washington (2011) for lagoon replacement with an MLE-based treatment plant. Likewise, one Model 1 $TEC_{3.0TN+0.1TP}$ option is based on cost data from Foess (1998), while the other $TEC_{3.0TN+0.1TP}$ option is based on a non-linear extrapolation of the best fit line to the Washington (2011) dataset. The Foess-based costs could be considered more appropriate for modular or package treatment units. Because there is some uncertainty about the ability of these systems to consistently meet low TEC limits and because the Foess reference is somewhat dated, the Washington (2011) data were extrapolated in order to provide a "high-end" estimate for a field-constructed BNR system with EBPR.

To develop lagoon-specific cost estimates, we first estimated costs for each of the TECs for each of the five model lagoons, resulting in a total of the 25 possible scenarios summarized in Table 4. Then we normalized the costs for each of these scenarios by dividing the total costs by the average *design* flow and the average *actual* flow associated with each model lagoon. Appropriate unit costs were than multiplied by the flow for each lagoon associated with each model lagoon to generate plant-specific cost estimates. Design flow was used as the costing basis whenever it was available. Where design flow for a given lagoon was not known/reported, actual flow was used as the costing basis instead (costs for 12 lagoons were based on actual flow instead of design flow).

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